

Developing Computer Aided Ceramic Glaze Recipes Using Local Raw Materials

The Nigerian Experiment

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Abstract

Although the traditional ceramic practices have been long in Nigeria, the full impact of the global advances in ceramic glaze technology is yet to be felt. Existentially, the prevailing approaches to glaze composition by local ceramic practitioners have remained hands-on trial and error methods including the use of already-prepared glazes which often do not deliver as expected due to unpredictable conditions. With the growing awareness on computer based glaze composition coupled with the need to improve glaze using materials from local sources; this study thus makes attempt on filling the existing gap between indigenous glaze quality tradition in Nigeria and the scientific prowess of modern glaze technology. To this end, multifaceted survey and glaze experiments was set up at exploring the potentials for developing computer aided ceramic glaze recipes based on existing local glaze recipes using available raw materials in Nigeria. The main experimental instruments included two sampled glaze software packages and 51 collections of locally tried glaze recipes. By adapting the software database for a new set of Nigerian raw materials, the study established the potentialities of an analytical approach to glaze formulation and the need to take advantage of the abundant ceramic raw materials in Nigeria for a time-saving, predictive and improved glazed ceramics production process. It is believed that this study could serve as a springboard to simplify glaze 'mysteries' and provide local ceramic practitioners with insight to explore the glaze tools and materials within their reach.

Keywords

Stoneware Glazes; Glaze Software; Glaze Chemistry; Computer Aided Glaze Design; Local Raw Materials

Introduction

Ceramic manufacturing is a time consuming process which begins with prospect for earthy inorganic minerals processed into suitable blends, and in turn used in forming products of preconceived shapes and later subjected to drying, heat treatment (firing) and

decoration. The latter process involves the application of glazes which in a firing process create value to clay-based ceramic products by impacting beauty, strength, protection, gloss, and aesthetic appearance. As inferred from several authors [Singer and Singer, 1963; Taylor and Bull, 1986; Rado, 1988; Buck, 1999], glaze is a glassy coating fixed on the surface of ceramic articles. It is formed by the melting of finely ground and thoroughly mixed rocks or earthen deposit. The preparatory process involves suspension in water of finely intermixed earthen insoluble materials which are applied to clay bodies as a thin surface coating [Colbeck, 1988]. When fired to appropriate temperature, these materials fuse with one another forming a molten solution which on cooling becomes a glassy coating on the clay body. Parmelee [1973] technically describes a glaze as thin continuous coating, usually prepared to form fused silicate mixtures fusion-bonded to ceramic surfaces.

The list of raw materials and quantities required to make a particular glaze for a particular firing temperature is referred to as the recipe. Ewing [2009] supports that each of those materials can be represented as a list of component oxides that will end up in the fired glaze. The glaze technology is therefore based on the fact that a number of oxides capable to form glasses (RO), such as silica, SiO₂ and boric oxide, B₂O₃ are commonly used in ceramics glazes. The high temperature melting point of silica is modified by basic fluxing oxides (RO/R₂O) such as potassium oxide, K₂O, sodium oxide, Na₂O, calcium oxide, CaO, magnesium oxide, MgO etc. while, a stabiliser (R₂O₃) such as alumina, Al₂O₃ is added to control and stiffen the glaze (Fig. 1). The composition of glaze is adjusted to ensure good adhesion to the surface of the ceramic body without running-off or overflowing during firing or heat treatment.



FIG. 1 BASIC GLAZE OXIDES IN A MOLECULAR COMBINATION

Gloss firing is the process that enables the application of a glassy coating (glaze) on a ceramic body, which may render the body smooth, non-porous, impervious, hygienic and of a desirable colour or texture. Essentially, this seemingly complex process offers a great deal of potential not only for permanence and utility but for aesthetic variations.

Historically, the development of glazes has notably stemmed from an accidental discovery in an era where scientific knowledge was rare. The long standing glazing tradition found in Greece, Mesopotamia, Egypt, and China are amazing references to early ceramic civilisation dated 8th or 9th century B.C or earlier [Gascoigne, 2001]. However, with a heightened advancement in material science, this antecedent had called for the need to achieve more pragmatic results through a scientific study of materials as the ages pass by. Rhodes [1972] posits that in order to make full use of the rich potentials of ceramic medium, the ceramists or potter needs not only skill, imagination, and artistic vision; but also a sufficient technical knowledge which can be best acquired through endless experimentation and discouraging failures. It was added that this technical information is a necessary prerequisite to a free and creative choices of different types of ceramics though it must not be considered as an end in itself. Today, it can be added that with the advent of glaze calculation software and availability of chemical material analyses, more control can be gained over the whole glaze formulation process.

Software development for glaze preparation led to the use of computers as tool to enhance the processes of formulating glazes. Since the late 1970's, various computer software packages have been developed internationally to assist ceramic students, artists and practitioners in their glaze chemistry. For example, Matrix2000 is glaze calculation software developed by Lawrence Ewing and Glaze Calculator by Christopher Green while HyperGlazeX and Insight are among notable glaze softwares widely used in North America by Richard Burkett and Tony Hansen respectively

[Rhodes and Hopper, 2010]. Basically, these computer aided programs have been developed as universal application and built with features that enhance most glaze calculation and formulation processes. Ewing [2009] notes that with the use of computer application, it is possible for ceramists to approach glaze experimentation from an analytical viewpoint focusing on the chemistry of the raw materials as it affects the fired glaze. Since most existing glaze softwares are open-ended but incomplete, without reliable analysis of specific local materials at disposal, their viability is most probably not guaranteed. This is because relying alone on the database of previously stored material analysis might not suffice to formulate a true glaze representative of the actual local materials available.

Considering the significance of glazes to clay-based ceramic product finishing and towards advancing glaze technology in Nigeria, this paper presents a research effort targeted at exploring the chemical potentials of locally available raw materials adaptable for glaze formulation using software. The inherent possibilities available through the understanding of materials with the application of scientific methods and computer applications, if properly harnessed, will profit indigenous small and medium scale ceramic production in Nigeria.

Research Background

The success of any ceramic industry largely depends on the consistency in the quality of its product output. In Nigeria, studies have shown that most ceramic industries suffer a lot of setbacks due to problems associated with discrepancies in product output and the realization of effective indigenous methods dependable for a sustainable production. In addition to other ill factors such as paucity of facilities and the electrical energy crisis, the resultant effect culminates at high production cost, under-utilisation of materials and poor product finishing. Romanosoglou, Alexandridis, Tsapoga, Papaioannoy and Karadimas [2010] acknowledged that the Small and Medium Enterprises (SMEs) face teething troubles in the area of formulating balanced and viable glazes. It was also observed that most local ceramic institutions studying the ceramics as an art had relegated the aspect of glaze formulation because of lack of glaze insight or appropriate working tools that could facilitate development of glaze from an analytical point of views.

The 1950s Anglo-Nigeria studio pottery movement according to Akinbogun [2009], can be said to be an evident foundational work for experimental glaze research in Nigeria. A notable proponent of this period was the prolific British potter, Michael Cardew who was appointed as a pottery officer at the Abuja pottery centre (now Ladi Kwali Pottery Centre, Suleja). Cardew's presence as a potter with vast knowledge of mineral sciences thus facilitated modern pottery production techniques which also imbibed the existing traditional styles. The result of this experiment was materialised through the achievement of workable stoneware glaze recipes developed manually using locally accessible raw materials processed with modern equipment [Cardew, 1969]. Based on the pioneering work of Michael Cardew followed up by Michael O'Brien, most established pottery enterprises especially in the Northern states of Nigeria thrived on locally available materials. These myriad of efforts has resulted in the establishment of various glazes which include ash glazes, Chun glazes, Tenmoku glazes (a transparent dark brown shiny glaze with lot of iron oxide), opacified glazes, variety of Celadon glazes and also matt glazes. With the establishment of ceramic institutions in Nigeria, experimental glaze researches continued to grow, however, most are conducted under unpredictable conditions using available raw materials and manual glaze composition technique.

With a retrospective perspective on the development of glazes in Nigeria relatively to the current trend, there will be a need to identify, characterize and analyse locally available raw materials for prospective local exploitation. While the local raw materials still remain largely untapped, and the introduction of analytical glaze formulation tools seems essential to facilitate insightful material exploration towards enhancing glazed ceramics production. Glaze calculation software will be a versatile tool in ceramist's toolbox as much as there is an availability of materials and reliable information of the materials' chemical analyses. This research therefore focused on experimenting ceramic glaze development with existing glaze software using samples of local glaze materials from selected locations in Nigeria (Fig. 2). A more predictive approach to developing new glaze recipes and expanding existing glazes was proposed. It is envisaged that the indigenous ceramic practitioners would benefit from increased knowledge of the ceramic materials in their disposal and the mastery of the production process.

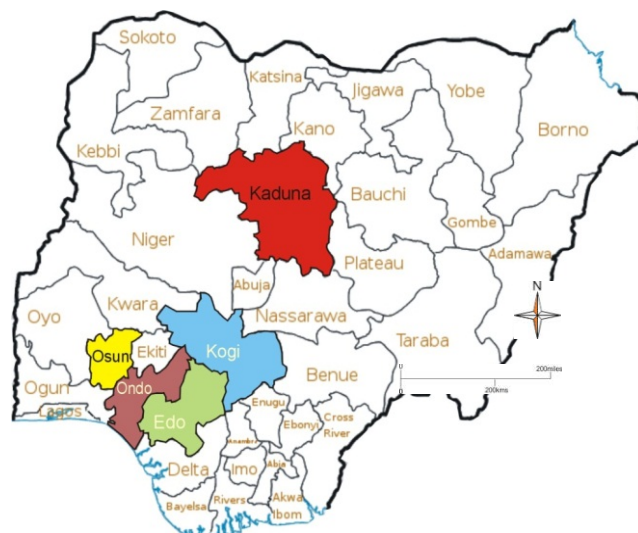


FIG. 2 LOCATIONS OF SELECTED RAW MATERIAL SOURCES IN NIGERIA

Method

The research design adopted both survey instruments and experimental approach. The survey phase involved field data collection while the experimental phase included studio and material laboratory tests. Fig. 3 below is an overview of the research procedure adopted for the study.



FIG. 3 THE RESEARCH PROCEDURE

Data Collection

The data for the study were drawn from both primary and secondary sources. The survey data was collected through administration of multi-choice questionnaire, oral interview, and opinions sampling. Data collection instrument for glaze materials include direct observation, physical and chemical characterization. The secondary data were sourced through selective information gathered from theses, technical reports, journal and relevant literatures in print and electronic format. Through purposive sampling, established local recipe samples for the study were gathered from a samples population of local potteries and ceramic enterprises actively operating in Nigeria, and public tertiary institutions in Nigeria offering ceramics programmes (see Table 1). Random sampling was used at eliciting respondent opinions within the sampling frame with a view to assessing the effects of local raw material utilization and glaze composition techniques on glazed ceramics production in Nigeria.

The rationale for adopting the sampling technique was based on proximity, convenience, and cost covering all units within research population [Kothari, 2004; Pameersselvan 2007].

Figures and Tables

Based on the research survey, population samples and data sourced are classified and shown in tables as follows:

TABLE I OVERVIEW OF SURVEY SAMPLE

Main data sources	Sample (n)	Location	Comment
Pottery enterprises (SMEs)	5	Kaduna, Abuja, Osun, Lagos	Active involvement in glaze pottery production based on indigenous recipes using local techniques and raw materials A contemporary studio outfit highly resourceful in glaze materials and facilities
Institutions of learning	10	Ondo, Ekiti, Kaduna, Lagos, Oyo	Includes universities, polytechnics and colleges of education where ceramic courses are offered
Research Institutes/ Material laboratory	3	Lagos, Oyo, Plateau	Laboratory equipped with facility for analysis of raw materials

TABLE II SOURCES OF SAMPLED LOCAL GLAZE RECIPES

S/N	Name	Location	Number of Recipes	Source
1.	Maraba Pottery	Kaduna	11	Primary and secondary
2.	Ushafa Pottery	Abuja	1	Primary
3.	Bwari Pottery	Abuja	5	Secondary
4.	Atamora Pottery	Osun	2	Primary
5.	Heritage Ceramics	Lagos	2	Primary
6.	Ceramics Department Ahmadu Bello University	Kaduna	5	Primary
7.	Ceramics Section Industrial Design Department, Federal University of Technology, Akure	Ondo	20	Primary and secondary
8.	Ceramics and Glass Technology Department, Auchi Polytechnic	Edo	5	Primary

TABLE III INVENTORY OF RECENT AND WIDELY-USED GLAZE SOFTWARE

Software name	Author/ Developer	Year of first release	Origin	Web Reference	Format / Cost (US\$)
Insight and Foresight	Tony Hansen	1979	Canada	http://digitalfire.com	Standalone/ 59
Hyper-Glaze	Richard Burkett	1989	USA	http://hyperglaze.com	Standalone/ 100
Matrix	Lawrence Ewing	1988	New Zealand	www.matrix2000.co.nz	Standalone/ 106
Glaze Calculator	Christopher Green	1998	Australia	http://www.glazecalculator.com.htm	Standalone/ Free
Glaze-Master	John Hesselberth	1999	North America	http://pondpottery.com	Standalone/ 50
Glaze Simulator	Fraser Forsythe	2000	North America	http://www.glazesimulator.com/	Web-based/ Free
Glaze-Chem	Robert Wilt	2001	USA	http://www.dinoclay.com/glazechem@dinoclay.com	Standalone/ 35

1) Raw Material Samples

Raw materials viable for glaze composition were primarily sourced from well-known sources and where they are also available at commercial quantities. The locations of the material samples as shown in Figure 1 above includes glaze materials from Edo (Auchi), Osun (Wasinmi), Ondo (Akure), Ekiti (Ekiti) states in the Southern Nigeria; Kogi (Lokoja) states in Central Nigeria; Kaduna (Zaria) and Plateau (Jos) states in the Northern states of Nigeria. The materials prospected for include kaolin, feldspar, quartz, dolomite, ball clay, bone ash, granite dust and whiting. Fig. 4 shows one of the local sources for the sampled and analysed materials.

TABLE IIv INVENTORY OF COLLECTED GLAZE MATERIALS AVAILABLE THROUGH LOCAL SOURCES

Material category	Sources with identical name
Quartz/Silica	Akwanga quartz, Auchi flint, Lagos silica sand, Lokoja Quartz, Igbokoda sand, Atamora granite dust
Feldspars	Zaria Potash Feldspar, Lokoja Potash, Auchi Feldspar
Clays	Bomo ball clay, Mowe ball clay, Auchi ball clay, Atamora ball clay, Auch kaolin, Kankara kaolin
Fluxes (Modifiers)	Auchi Whiting, Auch dolomite, Egg shell, Zinc oxide
Opacifiers, Colourants	Tin oxide, Iron oxide
Ashes	Wood ash (washed), Rice husk ash

The materials highlighted in grey were selected basic materials chemically analyzed and used for the formulation of new recipes



FIG. 4 GRANITE DUST SITE NEARBY A GRANITE ROCK PROCESSING PLANT IN OSUN STATE, NIGERIA

2) Local Recipe Samples

Purposively, some selected ceramic institutions and Small and Medium Pottery Enterprises Consultations were approached for their glaze recipes (mostly stoneware) which were adapted for the study. The ceramic enterprises and academic institutions visited were adjudged as reliable sources for the collection of established glaze recipes and information on locally available raw materials. Purposive sampling was adopted at the premise of wide coverage area and accessibility.

3) Glaze Software Samples

For the purpose of developing new recipes in a computer aided process, the study adapted two samples of widely-used glaze softwares which included Matrix2000 (version 6.01) and HyperglazeX (version 10) softwares (Fig. 5).

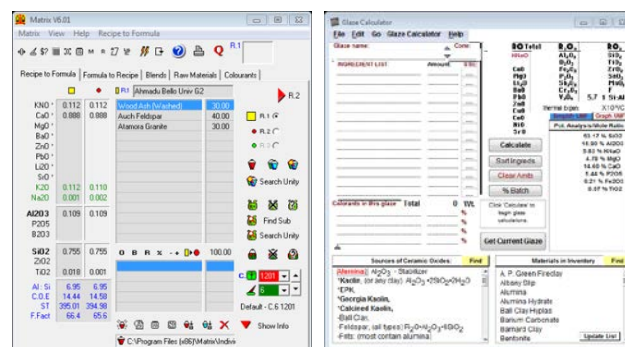


FIG. 5 USER INTERFACE OF SAMPLED SOFTWARES [MATRIX2000 BY LAWRENCE EWING AND HYPERGLAZEX BY RICHARD BURKETT]

4) Raw Material Analysis

The need to integrate fresh analyses of local raw materials into the material library of sampled softwares necessitated oxides analysis test for some selected local glaze materials. Percentage composition of the oxides contained in selected material samples- Auchi Ball clay, Auch Dolomite, Auch Feldspar, Atamora Granite, Calcined Egg shell, Calcined Bone ash. Three research centres were consulted for material analysis. Raw material samples were chemically analyzed in percentage and molar ratio at two material laboratories using X-ray fluorescence (XRF) spectrometry and Atomic Absorption Spectroscopy (AAS) respectively. The raw material samples analyses presented in Fig. 6 using Matrix2000 is the output of the X-ray fluorescence (XRF) spectrometry conducted at the National Metallurgical Development Centre, Jos, Nigeria (May 2011). The raw material analyses chart in Fig. 7 was presented with HyperGlaze2000.

	KNO	CaO	MgO	BeO	ZnO	PbO	Li2O	SiO2	B2O3	P2O5	SiO2	TiO2	ZrO2	K2O	Na2O	Fe2O3
Wood ash (washed)	7.950	77.030		0.660	0.045		0.740				0.700	0.520		7.960		2.000
Auchi Ball Clay	1.690	0.240			0.037	0.035	0.030	25.600			66.300	2.940	0.130	1.690		2.630
Auchi Feldspar	17.000			0.050	0.005	0.043	0.012	17.000			64.500	0.020		17.000		0.594
Atamora granite dust	6.010	7.570			0.036	0.043	0.190	15.000			54.000	2.420	0.072	6.010		13.990
Auchi Flint	0.653	0.110				0.015					97.200			0.653		1.680
Auchi Kaolin		1.120			0.015	0.085	0.044	40.300			49.600	5.640	0.787			1.570
Auchi whiting	0.240	97.650		0.080	0.003		0.853				0.030	0.008	0.240			0.414
Auchi Dolomite		42.400	17.000	0.080			0.140					0.030				0.475

FIG. 6 % ANALYSES OF RAW MATERIALS PRESENTED WITH MATRIX2000

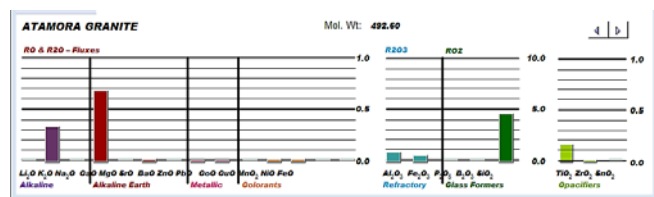


FIG. 7 ANALYSIS GRAPH GENERATED WITH HYPERGLAZEX
FOR A SINGLE RAW MATERIAL

5) Local Recipes Pre-test

The approach adopted by the study towards developing new glazes is to start with several locally-established glazes; serving as a springboard to formulating new ones using available local raw materials. The total number of fifty-one (51) local recipe samples was collected with information on their raw material sources. Two series of gloss test were done to confirm the suitability of the available raw materials for the collected recipe samples. The core glaze materials for the recipes included Kaolin, Feldspar, Flint, Whiting, Dolomite, Ball clay, Granite dust, Wood Ash, Rice husk ash, Bone ash from Edo, Osun, Ondo, Kogi and Kaduna States (Table 3). In order to provide suitable firing test facility, a gas test kiln of 31,773 cm³ capacity was developed. The recipes pre-test was done in two series by alternating materials obtained from Northern- and Southern-Nigeria. The gloss firing tests were carried out with gas kilns under stoneware temperature (1200°C-1235°C) and a reduction atmosphere.

6) *New Recipes Formulation*

With Matrix2000, the basic initial approach for new recipe formulation involved entering basic material analytical data in the software material database. Other succeeding tasks included entering of a pre-selected recipe, conversion of the recipe to formula; adjustment of the recipe formula using new material data stored in the software database; balancing the glaze oxides by Unity formula; and finally, reconverting formula back to a new recipe. Apart from accomplishing basic glaze design tasks, material blends, and batch calculation, the softwares can also be affordable to visually describe the new glaze limits, Alumina/Silica ratio, basic oxides ternary, and other useful information about the glaze characteristics. To this end, eight (8) new recipes were developed based from initial base recipes selected from pre-tested glaze recipes. The newly formulated recipes were tested under a reducing firing condition at 1200°C while the

outcome was assessed by glaze experts in terms of optical and tactile qualities.

Results

An assessment on the physical qualities of the pre-tested recipes using degree of melt and viscosity guided in the selection of eight recipe samples. Table 5 below shows three samples from pre-tested recipes which were selected as base recipes to formulate the new recipes.

TABLE V EXAMPLE OF SELECTED RECIPES AFTER PRE-TEST

Glaze Nomenclature	Recipe in %	Firing Condition
MG7	Feldspar :40.00 Ball Clay :30.00 Wood Ash :30.00	1205°C Reduction
ABG2	Feldspar :40.00 Wood Ash :30.00 Granite :30.00	1205°C Reduction
SAG1	Feldspar :60.00 Wood ash :20.00 Kaolin :10.00 Ball clay :10.00	1205°C Reduction

The chemical analysis of the material samples carried out through an X-ray Fluorescence Spectrometry (XRF) basically informed about the percentage composition of oxides contained in each material samples. Table 6 shows the calculated molecular weight of material samples with basic data classification required for the software raw material input processes.

The sampled softwares, HyperglazeX and Matrix2000 were adaptable for the new local materials which in turn enabled new glaze recipe designs. Table 7 shows three samples of the final outcome of computer aided formulated recipes. The following table presents the Limit formula for the principal oxides in the new recipes varying firing temperature. As compiled by Ewing [2011], Limit formula are oxide ranges which could be taken as rough guide for new glaze formulation and mostly within this limits, stable and functional glazes can be prospected for.

TABLE VI RAW MATERIAL ANALYTICAL DATA

Material Name and Nomenclature	Mol. Weight	Category	Molecular Analysis (part/mol.)
Auchi Ball Clay (ABC)	396.582	Clay	K ₂ O 0.071 Al ₂ O ₃ 1.000 SiO ₂ 4.391 Fe ₂ O ₃ 0.066 TiO ₂ 0.147 CaO 0.017 ZnO 0.002 SrO 0.001
Auchi Feldspar (AFELD)	547.794	Feldspar	K ₂ O 0.996 Al ₂ O ₃ 0.921 SiO ₂ 5.924 BaO 0.002 Fe ₂ O ₃ 0.021 TiO ₂ 0.001 MnO ₂ 0.001 PbO 0.001
Auchi Whiting (AWHIT)	57.035	Flux	CaO 1.000 K ₂ O 0.002 SrO 0.005 Fe ₂ O ₃ 0.002
Atamara Granite (AGRA)	493.676	Others	K ₂ O 0.317 Al ₂ O ₃ 0.732 SiO ₂ 4.466 CaO 0.671 ZnO 0.002 Fe ₂ O ₃ 0.436 PbO 0.001 SrO 0.009
Wood ash-washed (WASH)	66.353	Others	K ₂ O 0.057 SiO ₂ 0.098 CaO 0.935 Fe ₂ O ₃ 0.008 TiO ₂ 0.004 BaO 0.003 SrO 0.005

For the above listed raw materials, the predominant oxides are highlighted in grey with molecular parts from +0.4~

TABLE VII FINAL OUTCOME OF NEW RECIPES

Glaze Nomenclature	Recipe with sampled raw materials in %	Recipe Formula	Firing Condition
MG7NEW	AFELD :78.69 AKAO :7.08 AWHIT :14.23	KNO :0.36 CaO :0.64 Al ₂ O ₃ :0.41 SiO ₂ :2.31	1200°C Reduction
ABG2NEW	AFELD :85.20 AKAO :0.46 AWHIT :12.95 AFLIN :1.38	KNO :0.41 CaO :0.59 Al ₂ O ₃ :0.38 SiO ₂ :2.48	1200°C Reduction
SAG1NEW	AFELD :80.56 AKAO :8.34 AWHIT :11.10	KNO :0.43 CaO :0.57 Al ₂ O ₃ :0.49 SiO ₂ :2.70	1200°C Reduction

KNO indicate the combination of both K₂O and Na₂O (potassium oxide and sodium oxide)

TABLE VIII LIMIT FORMULAS FOR SELECTED GLAZE OXIDES

Oxides	Earthenware Cone 08 – 05	Mid Fire Cone 3 – 7	High Fire Cone 8 – 10
KNO	0.25 – 0.5	0.1 – 0.5	0.1 – 0.5
CaO	0.15 – 0.5	0.1 – 0.7	0.35 – 0.8
Al ₂ O ₃	0.1 – 0.25	0.2 – 0.35	0.3 – 0.55
SiO ₂	1.5 – 2.5	2.5 – 3.5	3 – 5

Source: [Latorre, 2009]

Findings and Discussion

From the field survey conducted by the study, it was revealed that glaze designed by computer aided tools is yet to be integrated into the Nigeria traditional ceramic practices. Most local ceramic practitioners are rather accustomed to glaze development through empirical approach. Besides, there was also a strong indication of low awareness among ceramic institutions on glaze formulation with computer software. Fig. 8 is a chart showing the general level of awareness to glaze software among a surveyed population sample which covered local ceramic practitioners- students, instructors, studio potters and technologists (for a sample population of n=56).

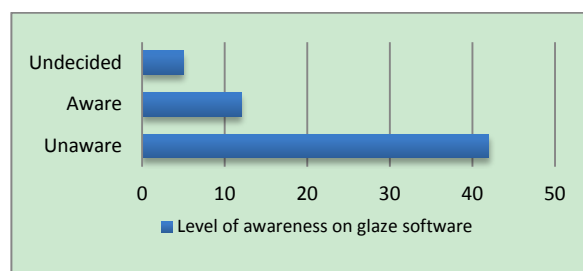


FIG. 8 LEVEL OF AWARENESS ABOUT GLAZE SOFTWARE [FIELD SURVEY 2011]

The study result proved the viability of sampled softwares for glaze formulation using indigenous Nigerian based materials. Nevertheless, it was noted that in order to fully realize the full capabilities of the available glaze softwares, the knowledge of local raw materials is highly required to enable the process of glaze formulation through computer aided tools. Since the softwares basically function based on the quality of information they are supplied with, their intelligent operation largely depends on the knowledge and manipulative skill of individual user. This is expected to be a point of interest for ceramic glaze technologists and experienced glazed pottery practitioners.

From the result of material sample analysis obtained through the XRF spectrometry, it was observed that calcium oxide (Na₂O), one of the prevalent fluxing oxides in glaze materials such as feldspar, was not accounted for. In addition to this limitation, a relative

comparison of the analytical results generated with both atomic absorption spectrometer (AAS) and the XRF spectrometer showed some variances. This variation posed a question at the level of reliability of data obtained from the materials analysis. For experimental studies which have the quality of their research output tied to the level of data accuracy, confirmatory tests will be inevitable. For this study, however, the result obtained through the XRF spectrometry proved more reliable because of its advancement over AAS technique. Banks and Altmann [2008] discuss common chemical analytical technique available including the ones applied for the study. It was noted that the atomic absorption spectroscopy (AAS) is perfectly quantitative when it is in the right hands and besides the X-ray fluorescence (XRF) spectrometry, the most accurate apparatus now used for routine chemical analysis is the high-resolution mass spectroscope, which can resolve a difference as small as one part in 10,000,000.

Considering the pioneering works of Michael Cardew and many local practitioners since 1950s, the study thus acknowledged the foundational effort on the development of glaze research in Nigeria. This is considered to be a springboard for more significant breakthrough. Since there are already-established glaze recipes in Nigeria used currently by active studio potters and ceramist practitioners and with the continuing efforts by local researchers and ceramic entrepreneurs, the exploration of the untapped local raw materials will be affordable compared to over-dependence on foreign materials. In spite of previous achievements, there will be a need to constantly review the ceramic production process on the background of current technological possibilities as agreed by Kashim and Akinbogun [2007].

An appraisal of the traditional method vis-à-vis the scientific approach somewhat shows that the former is liable to suffer much setback in terms of time efficiency, quick modification, accuracy and an analytical approach to glaze formulation. Without neglecting other significant factors that affect the glaze outcome and performance such as particle sizes of the raw materials, solubility of material particles, method and degree of glaze application on ware, heat work/firing condition, intrinsic reaction of raw materials in the melting process, and interaction glaze with underlying clay body, the study confirms the applicability and practicality of glaze software based on a sufficient understanding of the chemical

components of raw materials at disposal. The inherent capabilities of the existing software packages can provide the user with opportunity to perform a myriad of glaze tasks with less rigour yet with more possibilities of obtaining predictable results and saving time. While some raw materials are becoming inaccessible, the creative features of glaze software can enable ceramic practitioners to evolve with alternative material composition suited for any desired formula recipe. Although the physical nature of individual raw material could also influence glaze qualities even though there are other alternative materials that could be used to replicate their chemical composition.

TABLE IX SOME BASIC PROPERTIES OF NEW FORMULATED RECIPES

Glaze ID	New Recipe (%)	Al:Si	C.O.E	ST (Dynes/cm)	F.Fact
MG7 NEW	Feldspar :78.69 Kaolin :7.08 Whiting :14.23	5.67	13.90	364.81	40.7
ABG2 NEW	Feldspar :85.20 Kaolin :0.46 Whiting :12.95 Flint :1.38	6.53	14.07	355.47	39.9
SAG1 NEW	Feldspar :80.56 Kaolin :8.34 Whiting :11.10	5.58	13.74	362.12	37.2

Al:Si - Alumina Silica ratio; C.O.E - Coefficient of Expansion; ST- Surface Tension; F.Fact - Lengersdorff Flux Factor

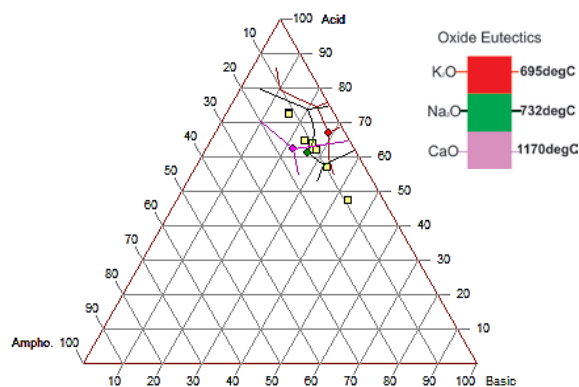


FIG. 9 TERNARY GRAPH FOR THE NEW RECIPES (MATRIX2000)

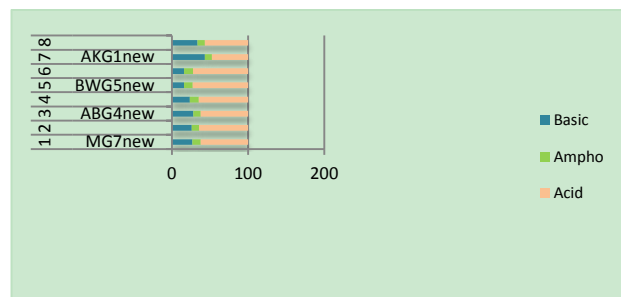


FIG. 10 A CHART SHOWING THE CONCENTRATION OF MAIN OXIDE CATEGORIES IN NEW RECIPES

In reference to Table 8 showing the limit formula stipulated to be used as guidelines for each oxide in the unity formula, a high level of compliance can be

observed. Limit formulas are list of stipulated ranges for each of the oxides in a glaze which is to be used as guidelines for each oxide in the unity formula. Though, it was also inferred from reference [19] that glazes can be composed of oxide amounts sitting within these ranges and yet not yield good results. As well, stable glazes can be obtained outside these ranges with special textures and characteristic effects.

Table 9 presents some technical properties of three new recipe samples. Fig. 9 and 10 describe the properties of all eight new recipes in terms of percentage (%) molecular parts of the oxides in the glaze. In Fig 9, each yellow box represents a glaze recipe while the networks of coloured lines identify the eutectic point for a particular temperature in the space of interaction among the glaze oxides. For instance, the eutectic patterns for K_2O , Na_2O and CaO (predominant flux oxides) indicated in the graph show the lowest melting for these oxides in interaction with certain levels of Al_2O_3 (amphoteric oxide) and SiO_2 (acidic oxides). The yellow box at the highest level represents recipe BWG5NEW which is closely accompanied with recipe KAG7NEW. At the lowest level is recipe AKG1NEW adjacent to recipe FAG3NEW. Fig. 10 depicts a distribution of the concentration of the basic, amphoteric and acidic oxides for all the new recipes. With the result of the new glaze firing test, recipes indicating close distribution patterns in the chart tended to exhibit similar attributes in terms of their physical qualities. For instance, recipes 1 to 4 have similar visual and tactile qualities of being transparent, glossy, smooth and stable while recipes 7 and 8 at the same time both have tendency to run.

Conclusion and Recommendations

This study attempted to proffer a step forward into a predictive and time-saving glaze formulation process especially for ceramic glaze researchers and pottery practitioners. To justify this proposition, a survey and experimentation was embarked upon to prove the viability of local raw material for glaze software applications. As a means to an end, available glaze raw materials were collected as well as locally established glaze recipes from selected ceramic studios and institutions in Nigeria. A pre-test involving the gloss firing of locally sampled recipes was carried out to confirm the viability of collected recipes with available materials and alongside, oxides composition analysis of selected glaze materials was done. Material analytical data obtained was adapted for the operation

of sampled glaze softwares in developing new recipe samples purely based on selected local raw materials. The study therefore considers computer aided glaze formulation as an approach to solving some problems associated with glaze developments. With the growing technology of glaze design and processing, taking full advantage of the abundant but underutilized local raw materials is encouraged. When local materials are effectively utilized, it creates impetus for industrial development, thus minimizing over-dependence on imported materials with its adverse effect on the economy [Adelabu and Kashim 2010; Kashim, 2011].

Though this study has proposed future research on the development of an home-grown glaze software solution for Nigerian raw materials, adapting the existing glaze software for glaze design and research will be a step towards satisfying the quest for a simplified glaze composition process/technique. This could help to meet the needs of ceramists for educational purposes, studio practices and glazed ceramic production in industry. With the various applications of computer-aided design to traditional ceramic processing, ceramic resources can be harnessed more effectively to ensure expected outcome for improved processes and quality product delivery for the SMEs related industries. This, in turn will position the local industries to out-turn products that will compete favorably in the global market in terms of functionality, ergonomics, aesthetics and other qualities that will also contribute to building a model and sustainable environment.

The study therefore recommends that institutions offering ceramic studies should consider adaption to the usage of glaze software for their glaze work. To facilitate this, the knowledge of the chemistry of materials and proficiency in the use of computers should be fostered through proper training by experienced personnel and technical staff that are versed in the concerned areas. Furthermore, a new approach to glaze experiments from analytical point of view and use of appropriate glaze processing facilities should be encouraged in various schools of technology that offers ceramics. Research institutes are beckoned upon to bridge the wide gap between the academic institution and industries by promoting and fostering original research works that seek to develop home grown solutions to improved ceramic glaze production in Nigeria. Raw material processing through the establishment of government or privately owned mining agencies must be revitalized. The government through its Ministry of Solid Mineral

Development and the Ministry of Science and Technology should set up mineral exploration team to identify, characterize and analyse major mineral deposits for local consumption. Government should also endeavor to develop formidable policies that will attract foreign investors in the mineral industries [Kashim and Adelabu 2010]. All these might not be an end in themselves, but together work as a sure means to a desirable end.

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